# Design of 5 K. W.-1,000 Ampere-110/5 Volt High Current Transformer

E. J. Wickersham
W. F. Parker
J. F. Kadic
A. W. Tyler

1 9 0 5

# DESIGN AND CONSTRUCTION OF

## 5 K. W. - 1,000 AMPERE - 110/5 VOLT HIGH CURRENT TRANSFORMER.

- - - - - - - - - - - -

A Thesis presented by

*E. J. Wickersham*

*W. H. Parker*

*J. F. Kadic*

*A. W. Tyler*

to the

President and Faculty

of the

Armour Institute of Technology

for the Degree of

Bachelor of Science in Electrical Engineering

Having completed the prescribed course of study in

Electrical Engineering.

*C. E. Freeman*
  *Per Snow.*

*H. M. Raymond.*
  *Dean of Engineering Studies*

*L. C. Monin*
  *Dean of Cultural Studies.*

Chicago, June 16th, 1905.

In the calibration of higher reading ammeters it is
necessary, on account of the high current required, to use
too large an amount of power to be economical when the current
is supplied at the normal voltage of an ordinary A. C. genera-
tor. For this reason it is advisable to use a transformer in
connection with the generator, which lowers the voltage and
gives a higher current, and only changes the power by an amount
equal to the losses in said transformer.

The ordinary transformers built and such as are in the
labratories of technical institutions are built for trans-
formations of about I,000 to I00, or possibly from I,000 to
50 volts. A generator, to supply current for calibration pur-
poses, should not be larger than 4 or 5 K. W. at the most, to
be economical. With this, the above transformer of I,000/I00
volts would then give a current of 50 amperes at I00 volts.
Then to obtain the higher current readings requires another
transformer in connection with this one. This second trans-
former would have to be specially designed on account of the
high current at its secondary.

The transformer which we think best suited for this pur-
pose and the design of which we have chosen for our thesis,
is one to transform from II0 (pri.) to 5 volts (sec). The
capacity to be such (5 K. W.) that a current of I,000 amperes
may be delivered at the secondary. This will easily encompass
the entire scale of the majority of the ammeters in use in any
technical institution and in the various commercial uses to

which ammeters are put;  as the higher reading ammeters (5,000
amperes, etc.) of course only take a shunted current and do
not take  a current higher than 1,000 amperes.

There is another field in which the above transformer
may be used;  that is, in electro-chemistry.  We know that the
heat developed in any circuit is represented by $I^2$ R -- $\underline{I}$ being
the current in amperes flowing in the circuit, and $\underline{R}$ the re-
sistance in ohms of the circuit.  From this we can see that
to obtain the maximum amount of heat with the least expenditure
of power, we must have the highest current with the lowest
voltage feasible, as the power is expressed by E I -- where
$\underline{E}$ is the voltage across the circuit.  From this discussion
it may readily be seen that the above transformer will also
be valuable in the electric furnace, where currents as high
as 1,000 amperes are required to give the necessary heat.

In designing a transformer certain conditions are imposed under which it is to operate, as the primary and secondary voltages, capacity, frequency of alternation and minimum allowable efficiency.

There are three methods of design which are as follows:

I.   Analytical Method;

II.  Trial and Error Method;

III. Empirical Method.

However if the given conditions call for a design that departs considerably from previous experience, the second method is the only one available. This consists in assuming various values for B, dimensions and shape of core, current density and number of turns of wire and selecting the trans- former best suited to the given conditions.

The first thing to be done in the design of a trans- former is to decide upon the type and the method of cooling. We decided that the core type was the best suited to our condi- tions, as it would be difficult to wind such heavy wire as we would necessarily have to use for high currents, on a shell type of transformer. In regard to cooling, air cooling will give very satisfactory results when using a core type of trans- former of this size.

We will now consider the general equation for a transformer, which is:-

$$ E = \frac{\sqrt{2}\,\pi\,N_p\,A\,B\,f}{10^8} \quad \text{volts, in which} $$

E = Counter, E. M. F.

$N_p$ = No. turns on primary,

A = Area cross section of core sq. in.,

B = Flux density (lines / $\Box''$ ),

f = Frequency.

The next thing to consider is, the conditions imposed upon the transformer; they are:-
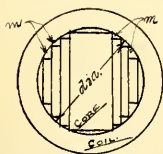
Capacity 5 K. W.

Secondary current I,000 amperes,

Primary voltage II0,

Frequency 60 cycles.

From this we can see that the only variables in the above equation are $N_p$, A and B. But for any value of A, B is a constant; this then narrows it down to $N_p$ and either A. or B as the variables. As we desire to construct the transformer



with the laminated core as shown in the accompanying sketch, it is advisable to assume a certain inside diameter of coil and from this calculate the values of A and B resulting; leaving the spaces m, m for air circulation to aid in cooling.

One other variable that does not come directly into the above equation is the current density in the coils, .This then leaves us with three variables to consider - - the number of turns on the primary, the diameter of core, and the density of current in coils.

We carried out a series of calculations with various

values of these variables, obtaining all data of the transformer
and its efficiency under all the various conditions which we
assumed. We limited the flux density in the core to 40,000
lines per sq. in. which seemed to be a maximum upper limit
consistent with good practice. The following is the complete
set of calculations with one set of assumptions, showing
method of calculation:

Design of 5 K. W. Transformer.

The assumptions are:-

    Current density - - I,000 circular mils per ampere,

    Number of turns on primary I32,

    Diameter core 3-I/2",

Data as given for design:-

    Capacity  5 K. W.,

    Current in sec.  I,000 amp.

    Voltage of primary  II0 volts,

    Frequency  60 cycles.

Primary Current  ($I_\rho$ )

$$I_\rho = \frac{E_\rho\, I_\rho}{E_\rho} = \frac{5,000}{II0} = 45.5 \text{ amperes.}$$

Size wire of primary coil.

    Since I,000 circular mils / amperes are allowed in
primary, and primary carries 45.5 amperes; circular mil area
will be 45.5 x I,000 = 45,500 circular mils. This is equiva-
lent to about 2 # 6  B & S wires.

(2 x 26,250 = 52,500 circular mils) will therefore be used.

Diameter = .I620 + .02 (which is the thickness of insula-
tion) = .I820, dia. of insulated wire.

Current in secondary is I,000 amperes; then

I,000 x I,000 = I,000,000 circular mils, required for sec.
This equals 785400 square mils.

Since two secondary coils will be in parallel, we have

$$\frac{785,400}{2} = 392,700 \text{ square mils / amperes,}$$

corresponding to

2" x I/4" copper ribbon = 500,000 sq. mils.
We will use 2-I/8" ribbons in parallel.

I/4 x 3 x (.02 x 3) = .8I" depth of series winding.

( .I35 x 2) x 2 = 2.27" outside dia. of spool.

Space occupied by primary coil :-

Since the primary should have the same thickness as
the secondary, then

$$\frac{.8I}{.I820} = 4+$$

Therefore we will have four layers.

Now the capacity of the transformer 5 K. W., divided
by I,000 amp. secondary current, $\frac{5,000}{I,000} = 5$ volts in

secondary. The ratio of transformation is

$$\frac{IIO}{5} = 22$$

With 132 turns on the primary we have $\dfrac{132}{22} = 6$ turns on the secondary.

In regard to the spacing of the coils, the best arrangement to reduce leakage, is to interlace the primary and secondary coils. So we will arrange the coils in this order on each leg of the transformer p,s,p,s,p; which makes six primary coils and four secondary coils in all, on the two legs; 132 turns on primary, and 6 primary coils makes $\dfrac{132}{6} = 22$ turns per coil. So we will have 22 turns of 2 #6 B & S, #80 D. C. wire, arranged as shown in accompanying sketch.
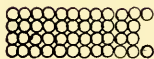


This gives 44 turns in all, or 12 turns wide in widest part.

12 x .182" = 2.184" space necessary for wire of one coil;

2.184 + (.155 x 2) = 2.45";

2.45" x 3 = 7.35" width of primary coils on one leg;

2.27" x 2 = <u>4.54"</u> . " " secondary coils on one leg;

II.89" " " all coils on one leg;

Allowing .04" between each coil = (.04 x 5) = .2" for clearance;

Allowing for bringing out leads $\dfrac{1}{4} + \dfrac{1}{4} + 3 ( .182) = 1.046"$.

Then total length over all coils is II.89" + .2" + 1.046" = 13. 136".

Average dia. primary coil is 3.5" + 1" = 4.5";

Then length of one pri. turn is $4.5\pi$ ";

length of 132 turns is $\dfrac{132 \times 4.5\,\pi}{12}$ = 155 feet.

Then we know that the resistance of any wire or rod is $R = \dfrac{\rho\, l}{A}$

where

$\rho$ = specific mil foot resistance of copper = 12;

$l$ = length of wire in feet;

$A$ = area of cross section of wire in circular mils.

Then the resistance of the primary coil is
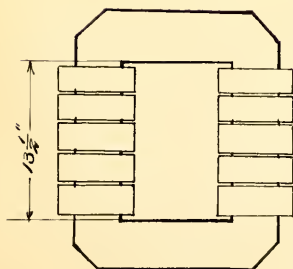
$\dfrac{12 \times 155}{52500}$ = .0354 ohms.

In the same way the resistance of the secondary coil is

$\dfrac{12 \times \left(\dfrac{6 \times \pi \times 4.5}{12}\right)}{1,270,000}$ = .000,067 ohms.

Then the total $I^2 R$ loss in the transformer is

$( \overline{45.5} \times .0354) + (\overline{1000} \times .000067) = 140$ watts;

$\dfrac{140}{5,000} \times 100 = 2.8\%$ copper loss at full load.



Net area of cross section of this iron is 7.8 sq. in., allowing 10% for insulation. Length of each leg is 13.5" between the ends as shown in this sketch of iron core, which leaves about .4" for clearance at ends of coils. Then the volume of these legs is 7.8 x 13.5 x 2 = 211 cu. in. To have

To have an area at the ends equal to 7.8, allowing for
~~champering~~ champhering, it is necessary to make the width 3".
Then the volume of the two ends is 2 x 7.8 x 10.5 = 149 cu in.
Total volume of iron is then – –

   211 + 149 = 360 cu. in.

The formula for the hysteresis loss is – –

   $H = V_i \; f \; \eta_m \; B^{1.6} \; x \; 10^{-7}$

$H = \dfrac{360 \times 60 \times .002 \times 40,000^{1.6} \times 10^{-7}}{\phantom{x}} =$

$H = \dfrac{360 \times 60 \times .002 \times 23,100,000}{10^{7}} = 97.6 \text{ watts}$

$\dfrac{97.6 \times 100}{5,000} = 1.98\% \text{ iron loss}$

   The full load efficiency then  is 100 – 2.8 – 1.98 =
95.4 % efficiency.

   In the same manner we carried out the calculations with
the above named assumptions.  The results of the calculations
are given in the following table.  In the case where we as-
sumed 88 turns on the primary coil it was found that the flux
density was too high as is seen by the figures shown.

Data from calculations of 5 K. W. high current Transformer.

60  Cycles --  $V_p$  110 -- $V_s$  5  --  $I_p$ 45. 45  --  $I_s$ -  1000

| Dia." | No of turns P | S | A□" | Vcu." | $(I^2R)_p$ | $(I^2R)_s$ | Total $I^2R\%$ | Iron loss% | Eff% | B/□" | ⊙mils/amp. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 3 | 132 | 6 | 5.6 | 230 | 65 | 59 | 2.50 | 2.01 | 95.49 | 54000 | 1000 |
| 3 1/4 | " | " | 6.7 | 291 | 69 | 63 | 2.64 | 1.99 | 95.5 | 46700 | 1 " |
| 3 1/2 | " | " | 7.8 | 360 | 73 | 67 | 2.80 | 2.00 | 95.4 | 40000 | " |
| 3 3/4 | " | " | 8.6 | 411 | 77 | 70 | 2.94 | 1.92 | 95.45 | 36600 | " |
| 4 | " | " | 9.9 | 474 | 81 | 74 | 3.10 | 1.71 | 95.4 | 31600 | " |
| 3 | 132 | 6 | 5.6 | 230 | 56.8 | 45.8 | 2.05 | 2.01 | 95.96 | 54000 | 1300 |
| 3 1/4 | " | " | 6.7 | 291 | 60.4 | 48.6 | 2.13 | 1.99 | 95.83 | 46700 | " |
| 3 1/2 | " | " | 7.8 | 360 | 64.1 | 51.6 | 2.21 | 2.00 | 95.79 | 40000 | " |
| 3 3/4 | " | " | 8.6 | 411 | 67.5 | 54.2 | 2.43 | 1.92 | 95.65 | 36600 | " |
| 4 | " | " | 9.9 | 474 | 70.3 | 57.0 | 2.54 | 1.71 | 95.75 | 31600 | " |
| 3 | 132 | 6 | 5.6 | 230 | 51.4 | 39.4 | 1.82 | 2.01 | 96.17 | 54000 | 1500 |
| 3 1/4 | " | " | 6.7 | 291 | 54.6 | 41.8 | 1.93 | 1.99 | 96.08 | 46700 | " |
| 3 1/2 | " | " | 7.8 | 360 | 57.8 | 44.4 | 2.02 | 2.00 | 95.98 | 40000 | " |
| 3 3/4 | " | " | 8.6 | 411 | 61.1 | 46.8 | 2.16 | 1.92 | 95.92 | 36600 | " |
| 4 | " | " | 9.9 | 474 | 64.0 | 49.0 | 2.18 | 1.81 | 96.01 | 31600 | " |
| 3 | 176 | 8 | 5.6 | 230 | 87 | 78 | 3.31 | 1.35 | 95.34 | 41800 | 1000 |
| 3 1/4 | " | " | 6.7 | 291 | 92 | 84 | 3.52 | 1.30 | 95.18 | 35000 | " |
| 3 1/2 | " | " | 7.8 | 360 | 97 | 89 | 3.71 | 1.26 | 95.03 | 30000 | " |
| 3 3/4 | " | " | 8.6 | 411 | 103 | 93.5 | 3.93 | 1.18 | 94.89 | 27200 | " |
| 4 | " | " | 9.9 | 474 | 108 | 97. | 4.10 | .97 | 94.93 | 23600 | " |
| 3 | 176 | 8 | 5.6 | 230 | 75.7 | 61.0 | 2.73 | 1.35 | 95.93 | 41800 | 1300 |
| 3 1/4 | " | " | 1.7 | 291 | 80.5 | 64.9 | 2.91 | 1.30 | 95.79 | 35000 | " |
| 3 1/2 | " | " | 7.8 | 360 | 85.5 | 68.6 | 3.08 | 1.26 | 95.66 | 30000 | " |
| 3 3/4 | " | " | 8.6 | 411 | 90 | 72.4 | 3.25 | 1.18 | 95.57 | 27200 | " |
| 4 | " | " | 9.9 | 474 | 95 | 76.0 | 3.42 | .97 | 95.61 | 23600 | " |
| 3 | 176 | 8 | 5.6 | 230 | 68.7 | 52.0 | 2.43 | 1.35 | | 41800 | 1500 |
| 3 1/4 | " | " | 6.7 | 291 | 72.8 | 52.8 | 2.57 | 1.30 | | 35000 | " |
| 3 1/2 | " | " | 7.8 | 360 | 77.2 | 59.2 | 2.73 | 1.26 | | 30000 | " |
| 3 3/4 | " | " | 8.6 | 411 | 81.5 | 62.5 | 2.83 | 1.18 | | 27200 | " |
| 4 | " | " | 9.9 | 474 | 85.0 | 64.0 | 2.93 | .97 | | 23600 | " |

| Dia." | No of Turns P | S | $D"$ Area | $cu"$ Vol | $(I^2R)$ | $(I^2R)^2$ | Total I R% | Iron loss% | Eff% | $B/D"$ | omils per arm |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 3 | 88 | _ | 5.6 | 230 | | | | | | 83900 | I000 |
| 3 I/4 | " | " | 6.7 | 29I | | | | | | 70000 | " |
| 3 I/2 | " | " | 7.8 | 360 | | | | | | 60000 | " |
| 3 3/4 | " | " | 8.6 | 4II | | | | | | 54400 | " |
| 4 | " | " | 9.9 | 474 | | | | | | 47200 | " |
| | | | | | | | | | | | |
| 3 | 88 | 4 | 5.6 | 230 | 37.I | 30.5 | I.35 | +.35 | | 83900 | I300 |
| 3 I/4 | " | " | 6.7 | 29I | 40.4 | 32.3 | I.45 | | | 70000 | " |
| 3 I/2 | " | " | 7.8 | 360 | 42.6 | 34.4 | I.54 | | | 60000 | " |
| 3 3/4 | " | " | 8.6 | 4II | 45.I | 36.3 | I.62 | | | 54400 | " |
| 4 | " | " | 9.9 | 474 | 48.I0 | 38.I | I.72 | | | 47200 | " |
| | | | | | | | | | | | |
| 3 | 88 | 4 | 5.6 | 230 | 34.4 | 36.3 | I.2 | | | 83900 | I500 |
| 3 I/4 | " | " | 6.7 | 29I | 36.7 | 27.9 | I.39 | | | 70000 | " |
| 3 I/2 | " | " | 7.8 | 360 | 38.5 | 28.6 | I.34 | | | 60000 | " |
| 3 3/4 | " | " | 8.6 | 4II | 40.3 | 31.2 | I.43 | | | 54400 | " |
| 4 | " | " | 9.9 | 474 | 42.2 | 32.8 | I.50 | | | 47200 | " |

Flux Density too high

From these calculations we decided ~~that~~ *to use* the 3 I/2" core
with I32 turns on the primary and six turns on the secondary and
with a current density of I500 circular mils per ampere.

It has been found by experience that for a transformer
operating under full load conditions, the iron losses should be
made practically equal to the copper losses for best results.
The calculations made with the above chosen assumptions, giving
the best efficiency, also answer these conditions.

The next thing we did was to obtain a test ring of
laminated iron of the quality which we expect to use in the con-
struction of the transformer, and insulated in the same manner.
On this ring were wound a primary and a secondary coil.

We decided to first obtain a B - H. curve for the iron
in this sample ring, in order to ascertain whether the quality was
of a suitable grade to be used in the construction of the trans-
former core.  In order to do this it was necessary to make use of
a ballistic galvanometer, in the Ewing's Ring Method of Deter-
mining a B - H. curve.

Before using this galvanometer we found that it was
necessary to accurately obtain its constant K, which constant
represents the deflection, in millimeters, of the moving system
of the galvanometer, upon the application of one coulomb  of
electricity, at its terminals.

The method used to determine this constant was to charge
a standard one-third microfarad condenser at certain known voltages

and then discharge same through the galvanometer noting the result-
ant deflection

Then we have

$$Q = K \rho$$

$$\& \quad Q = C E$$

Hence $\quad K \rho = C E$

$$K = \frac{C E}{\rho}$$

Where $Q$ = quantity. in coulombs

$K$ = galvanometer constant

$C$ = capacity in farads

$E$ = E. M. F. in volts

$\rho$ = Deflection in mm

The results we obtained were as follows:-

| Voltage | $\rho$ in mmv. | $\rho$ per volt |
|---------|------------|-------------|
| I | 72 | 72 |
| 2 | I52 | 76 |
| 3 | 2I7 | 72 |
| 4 | 270 | 75 |

Average $\rho$ per volt = 74.

Substituting in above equation for K, we have $K = \dfrac{\frac{1}{3} \times 10^{-6} \times I}{74} =$

$45 \times 10^{-10}$

Having obtained this constant we then proceeded to deter-
mine the B-H curve. To do this we send a known current through
the primary coil, which gives a value of H. which can be calcu-
lated from the formula H = $\frac{4\pi n_1 I}{10 L}$, where

H = strength of field

$n_k$ = number of turns on primary coil

I = current in amperes in    "       "

l = mean length of ring in cm

Then the flow of the current in the primary induces a current in
the secondary which causes a deflection of the moving system of
the galvanometer.  From this we can calculate the value of B
corresponding to this value of H, with the formula

$$B = \frac{10^8 \, R \, K \, \rho}{2 \, n_s \, A} \quad \text{in which}$$

B = flux density in lines $/\square$ cm

R = resistance of galvanometer circuit

K = galvanometer constant

$\rho$ =        "            deflection in mm

n = number of turns on secondary coil

A = area of cross section of iron ring in $\square$ cm

This gives the maximum value of $B = B_{mw}$ for the intermediate
values of B, decrease the flux H. from the maximum to the point
desired and no reversal is necessary.

In the case $B_1 = \dfrac{10^8 \, R \, K \, \rho}{n_s \, A}$ in which B. is the difference between
the maximum flux and the flux for the point desired.  Then to
obtain the flux for the point desired $= B_2$ , we have $B_2 = B - B_1 =$

$$B - \frac{10^8 \, R. \, K. \, \rho}{n_s \, A}$$

Obtaining a number of values of B & H. in this manner, which are
given below, we found upon plotting the accompanying B. H. curve

for the sample, that we obtained a hysteresis loop of small area
and as this area represents the amount of energy lost by hysteresis,
per cycle, we can see that this is a very good quality of iron for
the purpose.

The data and results of this test are as follows :-

Primary Coil = 220 turns $\#$ 14   B & S

Secondary " = 660   "  $\#$ 22   " "  "

Weight of iron = 9.907 $\#$

Inside dia. ring = 10.5" = 26.67 cm

Outside "    "   = 12.5" = 31.78 cm

Area of cross section of ring = 6.37$\Box$ cm

K = galvanometer constant = 45 X 10$^{-10}$

Then Bm = $\dfrac{10^{3} R K P}{2 \mu_{s} A}$ = $\dfrac{10^{8} \times 780000 \times 45 \times 10^{-10} \times 372}{2 \times 660 \times 6.37}$ = 15.520

| I(amperes) | R ( ohms ) | $\rho$ = def in mm | $\dfrac{10\ R.K.P.}{n_s\ ft.}$ | H | B lines /$D$ cm |
|---|---|---|---|---|---|
| 0 | 200000 | 215 | 4610 | 0 | 10910 |
| .5 | | 160 | 3425 | 1.565 | 12095 |
| 1.0 | | 84 | 1800 | 3.140 | 13720 |
| 1.5 | | 61 | 1307 | 4.71 | 14113 |
| 2.0 | | 51.5 | 1103 | 6.28 | 14417 |
| 2.5 | | 43.0 | 922 | 7.85 | 14598 |
| 3.0 | | 37.0 | 792 | 8.42 | 14728 |
| 3.5 | | 33.0 | 707 | 9.99 | 14813 |
| 4.0 | | 23.0 | 492 | 11.56 | 15028 |
| 4.5 | | 24.0 | 514 | 12.13 | 15006 |
| 5.0 | | 23.5 | 503 | 13.70 | 15017 |
| 5.5 | | 20.0 | 428 | 15.27 | 15092 |
| 6.0 | | 17.0 | 364 | 16.84 | 15156 |
| 6.5 | | 14.0 | 300 | 17.41 | 15220 |
| 7.0 | | 10.0 | 214 | 18.98 | 15305 |
| 7.5 | 100000 | 20.0 | 214 | 20.55 | 15306 |
| 8.0 | | 15.5 | 166 | 23.69 | 15354 |
| 8.5 | | | | | |
| 9.0 | | 5.0 | 54 | 26.83 | 15466 |
| 9.5 | | | | | |
| 10.0 | | 0 | 0 | 30.07 | 15520 |
| -,0 | 700000 | 61.5 | 4620 | 0 | 10900 |
| -.5 | | 271 | 20800 | 1.565 | 5280 |
| -1.0 | | 343 | 25700 | 3.14 | 10180 |
| -1.5 | | 368 | 27600 | 4.71 | 12080 |
| -2.0 | | 383 | 28700 | 6.28 | 13180 |
| -2.5 | 780000 | 347 | 29000 | 7.85 | 13480 |
| -3.0 | | 352 | 29400 | 8.42 | 13880 |
| 3.5 | | 360 | 30100 | 9.99 | 14580 |
| 4.0 | | 364 | 30400 | 11.56 | 14800 |
| 4.5 | | 365 | 30500 | 12.13 | 14980 |
| 5.0 | | 364.5 | 30450 | 13.70 | 14980 |
| 5.5 | | 368.0 | 30700 | 15.27 | 15180 |
| 6.0 | | 365.0 | 30500 | 16.84 | 14980 |
| 7.0 | | 366.5 | 30600 | 18.98 | 15080 |
| 8.0 | | 369.5 | 30900 | 23.69 | 15380 |
| 9.0 | | 371.0 | 31000 | 26.83 | 15430 |
| 10.0 | | 372.0 | 31040 | 30.07 | 15520 |
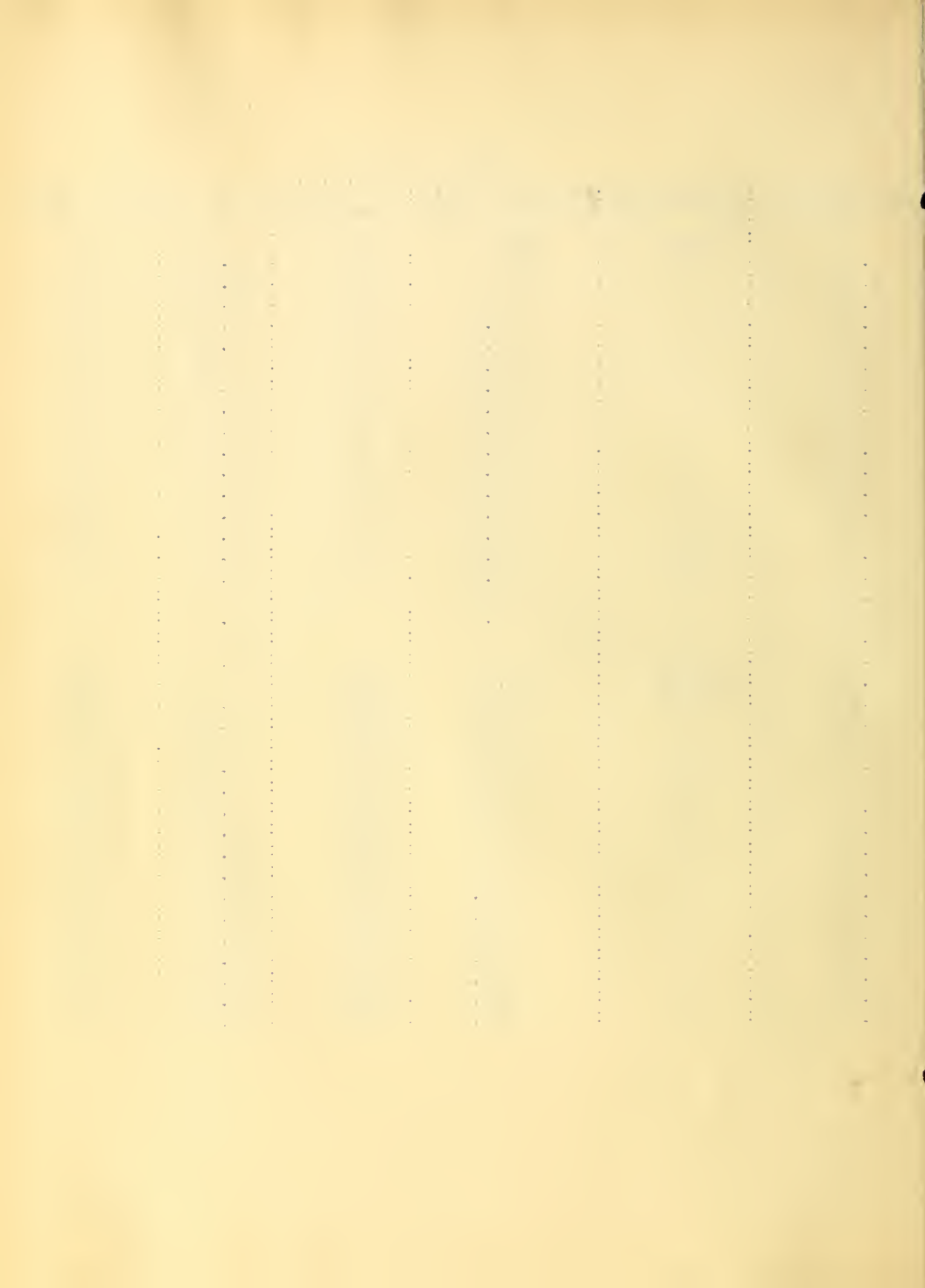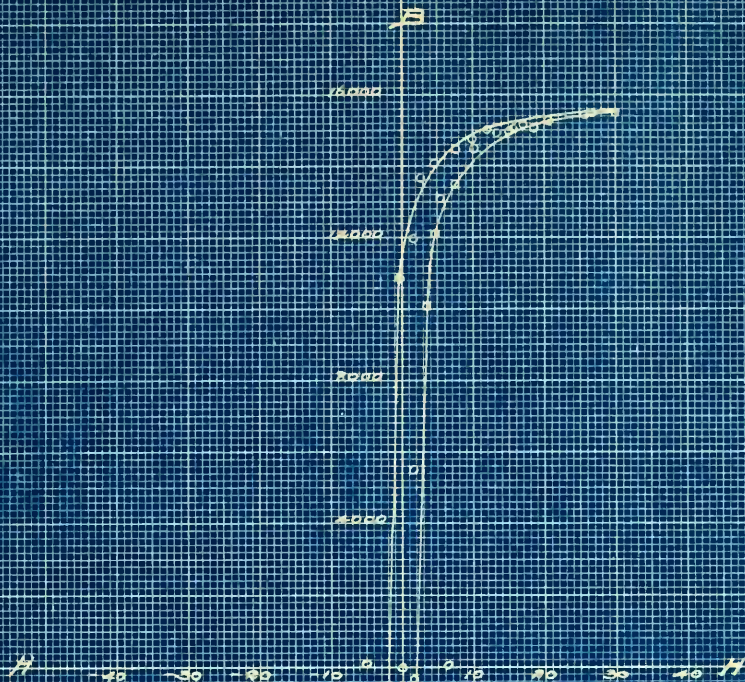
B-H. Curve
and
Hysteresis Loop
for
Sample Iron Test Ring
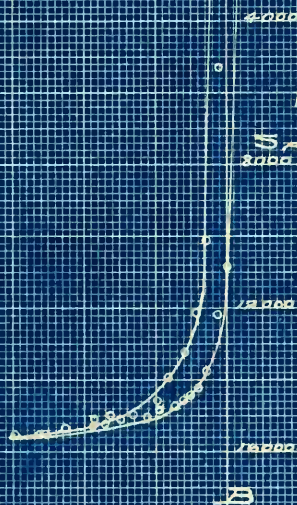
Calibration Curve
for
Wattmeter #6298
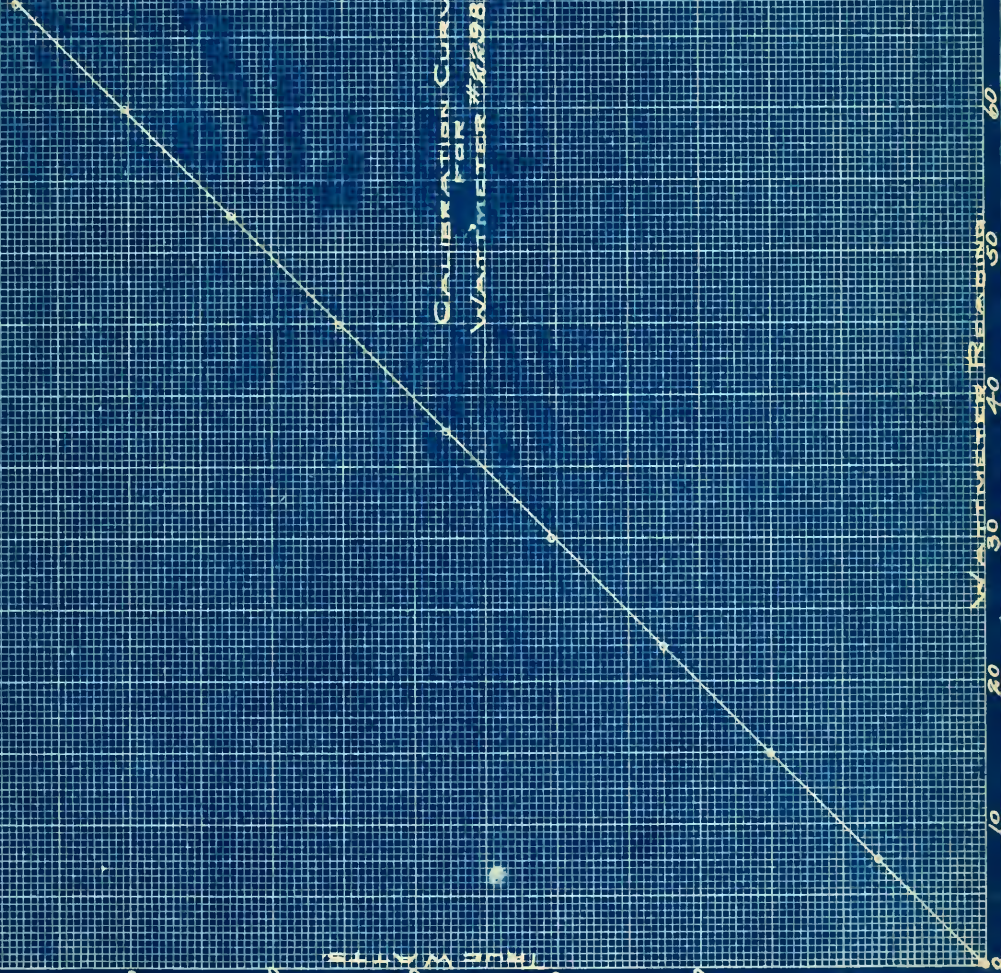
After determining that the iron was of a good quality for use in the construction of the transformer, we next determined the iron loss of the sample of iron, by the open circuit second-ary method; the scheme of which is as shown in accompanying sketch. We know that with the second-ary circuit of any transformer open, the only current which flows in the primary circuit is the exciting current, which is made up of two components at right angles; one the magnetizing current, which is the current required to magnetize the core of the transformer and which is $90°$ behind the impressed E. M. F. and therefor the wattless component. The other component of the exciting current, is that required to make up for the iron losses in the machine. This current is in phase with the E. M. F. and the product of the two multiplied by the power factor, will give the iron loss in watts and is the reading of the wattmeter in the accompanying scheme. The results of this determination are as follows:

| Volts | Wattmeter reading Watts loss | corrected Watts loss | B/☐cm | I | B/☐" |
|---|---|---|---|---|---|
| IO | 2.3 | 2.3 | 2680 | .30 | 17300 |
| 20 | 6.5 | 6.5 | 5360 | .40 | 34600 |
| 25 | 9.5 | 9.6 | 6700 | .45 | 43700 |
| 30 | IO.5 | IO.6 | 8240 | .50 | 53200 |
| 40 | I4.7 | I4.8 | IO720 | .60 | 68000 |
| 50 | 24.3 | 24.5 | I3400 | .75 | 86500 |
| 60 | 33.7 | 34.0 | I6080 | I.I5 | 108700 |

Iron Loss Curve
for
Sample Iron Test Ring.

We used the secondary, or coil with greater number of turns, as the primary coil, because more accurate results are obtained than would be if we had used the other coil.

By varying the excitation of the generator we obtained the voltages impressed on the ring transformer, given in the first column of the data and also the corresponding reading, of the exciting current and watts iron loss. The values of B. given are calculated with the formula $B = \dfrac{10^8 \, E}{\sqrt{2} \, \pi \, A \, f \, n_p}$ , obtained from the general formula for the transformer given in a former part of this thesis.

We obtained a calibration curve for the wattmeter, given on the accompanying page, from which we found the correct watts corresponding to the reading taken.

Now we know that the iron loss varies directly as the volume of iron. By calculation we found the net volume of iron of the transformer to be 360 cu. in. The volume of the iron test ring is 36.7 cu. in. By calculation the iron losses in the transformer was 2 % or 100 watts at a density of about 43000 lines per sq. in. From the iron loss curve for the ring, the iron loss at a density of 43000 lines per sq. in is 9.6 watts. As the volume of the ring is about 1/10 of the calculated volume of the transformer iron. 9.6 x 10 = 96 watts is the iron loss of the transformer as obtained in this manner, which agrees very closely with the calculated value.

As we expected to obtain the material for the construction

of the transformer from the Western Electric CO. of Chicago, we obtained a list of the sizes and styles of wire which they had in stock, from which we chose the sizes corresponding to the current densities and areas required for the coils of the transformer.

We finally settled upon the following, as the best suited for the construction of the transformer, taking into consideration both cost and time of delivery of goods to us.

Primary coils (current density 1500 ⊘ mils per ampere) 132 turns of # 2 square wire as shown in accompanying drawing. (We found later that we would have to change this to # 2 B. & S., # 60 Double Cotton covered round wire, as the cost of the former proved to be too great). We used six coils in series and 22 turns per † coil.
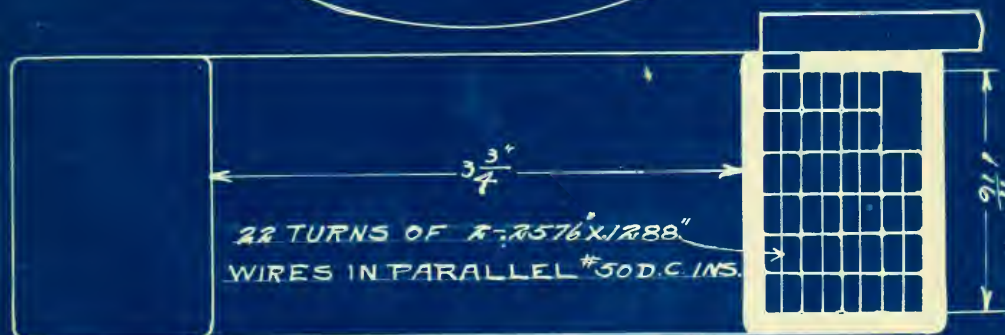
Secondary coils - Current density 1500 square mils per ampere.

Six turns of # 9 B & S. copper ribbon, 2 - 1" wide and 3 wires in parallel, making 6 ribbons in all and 3 turns per coil. Four coils to be connected either in series or in parallel. When connected in series, the secondary current is 500 amperes, and when connected in parallel the secondary current is 1000 amperes.
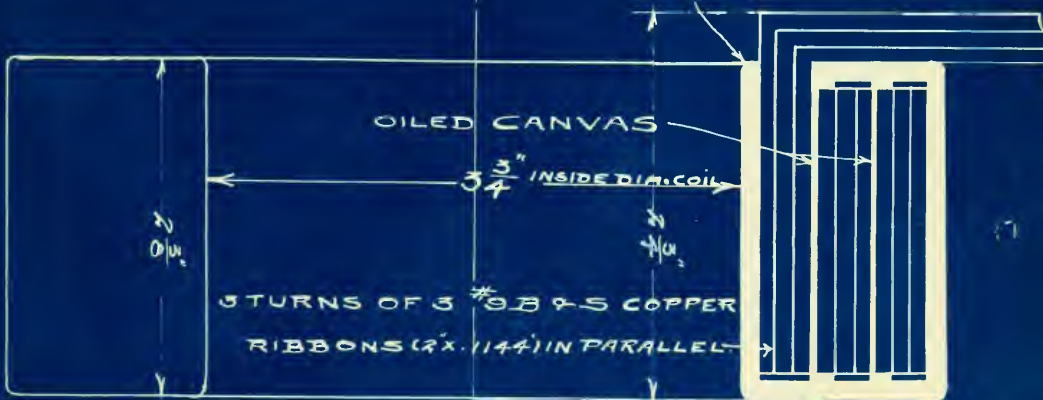
Assuming .015" as the thickness of the laminations, we found, by dividing the width of iron of each size by .015 the number of sheets of metal necessary for each part of the curve. For instance

PRIMARY COIL—6

$3\frac{3}{4}''$

22 TURNS OF $\pi=.2576''\times.1288''$
WIRES IN PARALLEL #50 D.C. INS.

$2\frac{7}{16}''$

SECONDARY COIL-4

⅜" PRESSBOARD

5¼"

TAPE

OILED CANVAS

3¾" INSIDE DIM. COIL

2 0/IN"

2 4/IN"

3 TURNS OF 3 #9 B & S COPPER

RIBBONS (2"×.1144") IN PARALLEL

5 K. W. TRANSFORMER PUNCHINGS.

200 PIECES WITH $A = 1\frac{7}{8}$"
" " " $A = 1\frac{3}{8}$"
$72$ " " $A = 1\frac{5}{32}$"
$60$ " " $A = \frac{3}{4}$"

ALL ROLLED ANNEALED AND PAINTED.

200 PIECES WITH $A = 3\frac{1}{8}$"
$92$ " " $A = 2\frac{22}{32}$"
$72$ " " $A = 2\frac{5}{16}$"
$60$ " " $A = 1\frac{7}{8}$"

ALL ROLLED ANNEALED AND PAINTED.
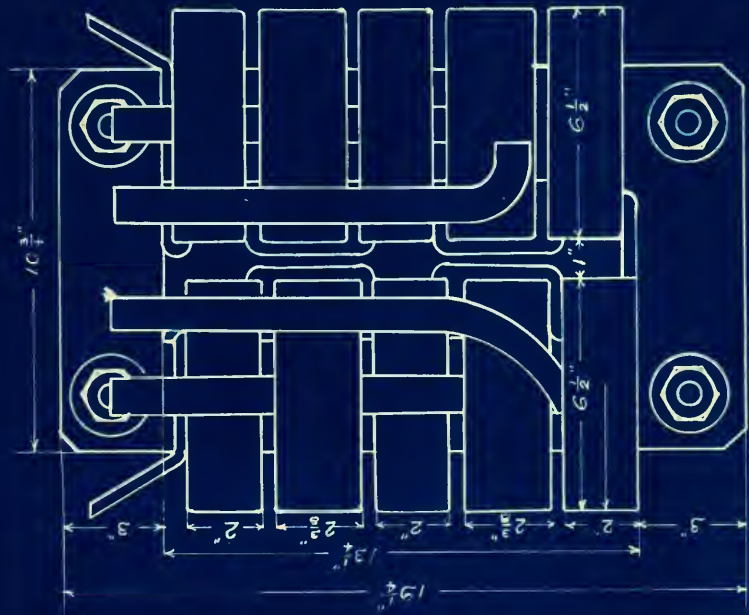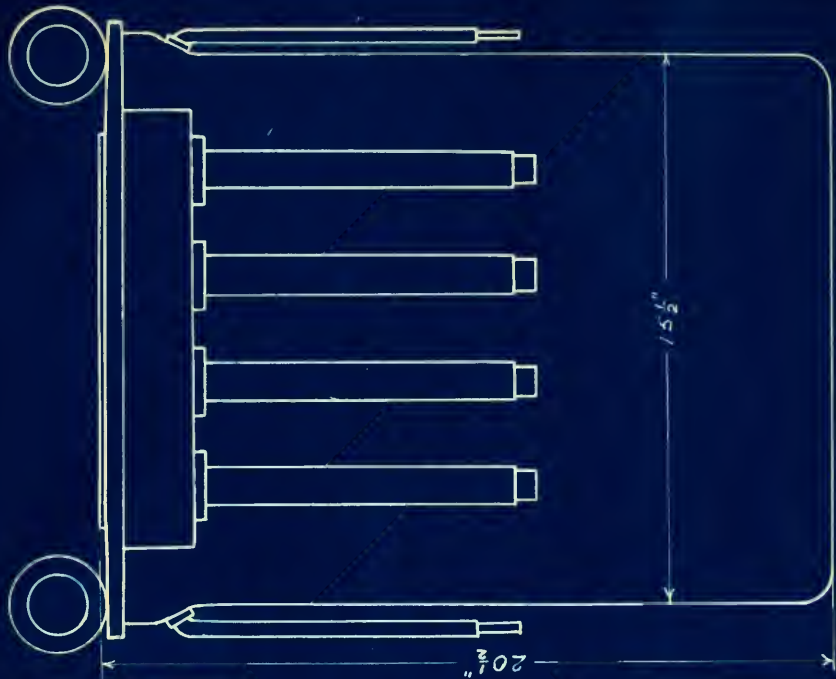
5 KW TRANSFORMER 110 V PRIMARY 5 OR 10 V. SEC.

in the accompanying sketch the pieces for each leg, that were to be 3 1/8" wide, would have to fill I 1/2" in width on each leg, making 3" for both legs.

Then $\dfrac{3}{.015}$ = 200 sheets of metal necessary as is seen on accompanying drawing. No account of insulation was taken in this case, as we wished to have several extra ones on hand, in case any of them proved defective in any way.
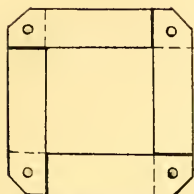
The pieces are assembled as shown in the accompanying sketch, the laminations being changed with regard to the position of the joint a, a., so that the joint will not come at the same place, with each lamination, as this would cause a sort of an air gap, which would require a higher exciting current and tend to decrease the efficiency of the transformer.

The transformer as it will appear when assembled is shown by the accompanying blue print.

The bottom and the two legs of the core are first assembled, the bottom being clamped together with the wood clamps as shown. Then on each leg is wrapped, pressboard I/8" thick. The coils are placed on the outside of this, and then the upper part of the core is assembled and clamped as shown.